

## Chapter 2

# Monitoring Inspection for Radioactive Substances in Agricultural, Livestock, Forest and Fishery Products in Fukushima Prefecture

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**Abstract** We summarize the inspections of radiocesium concentration levels in agricultural, livestock, forest and fishery produced in Fukushima Prefecture, Japan, for 3 years from the nuclear accident in 2011. The ratio in which radiocesium concentration exceeded the 100 Bq/kg from March 2011 to June 2011 was 18 % in agricultural products (excluding rice), 3 % in livestock productions, 49 % in forest productions, and 52 % in fishery produced. After June 2011, radiocesium concentration reduced drastically. Radiocesium concentration in agricultural and livestock products hardly exceeded the 100 Bq/kg. On the other hand radiocesium concentrations of forest and fishery products have been falling every year, but there were a little high concentration samples. Soybean is one of the agricultural products, and the radiocesium concentration is higher than the other agricultural products. We analyzed the absorption process in soybean in contaminated areas. The radiocesium concentration of the above-ground part was lateral root > leaf=petiole=pod > stem=main root. There was a difference in concentration ratio of radiocesium: potassium among parts of the plant. Comparing 10 soybean varieties, radiocesium concentration of wild soya bean showed more than twice as high as other varieties. And the radiocesium inside the soybean grain was distributed generally uniformly throughout the entire grain.

**Keywords** Monitoring inspection • Agricultural products • Livestock products • Forest products • Fishery products • Radiocesium • Fukushima prefecture

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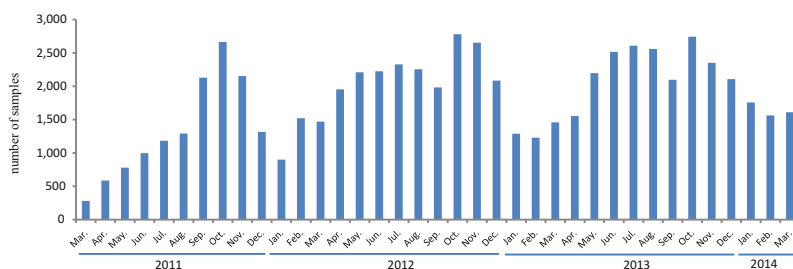
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## 2.1 Introduction

The Great East Japan Earthquake occurred on March 11, 2011, and was immediately followed by the accident at the Fukushima Dai-ichi Nuclear Power Plant (NPP) of Tokyo Electric Power Company (hereafter referred to as the nuclear accident). Radioactive materials released during the accident reached agricultural lands in Fukushima and neighboring prefectures and contaminated the soil and agricultural products (Yasunari et al. 2011; Zheng et al. 2014). To fulfill the requirements of the Food Sanitation Act in Japan (Law No. 233 issued in 1947), on March 17, 2011, the Ministry of Health, Labor and Welfare, Japan (MHLW) established a provisional regulation level of 500 Bq/kg for radiocesium in cereals, vegetables, meat, and fishery products. In April 1, 2012, a new maximum limit of 100 Bq/kg was established as a new standard of radiocesium in general food excluded infant food, milk, water and beverages (Hamada et al. 2012). To revitalize agriculture within the prefecture, Fukushima Prefecture has been promoting the decontamination of agricultural land while implementing radioactive substance absorption suppression measures for agricultural products. To verify the safety of agricultural, livestock, forest, and fishery products, the Nuclear Emergency Response Headquarters have been conducting emergency environmental radiation monitoring of agricultural and fishery products (hereafter referred to as monitoring inspections) as part of the emergency response in accordance with the special measure of the Nuclear Disaster Act in Japan. Targeted items and sampling locations for the monitoring inspections are determined by discussions with municipalities, consideration of the amount of production, and value of any shipment. When the results of a monitoring inspection indicate that the level of radiocesium exceeds 500 Bq/kg (the provisional regulation level, from March 17 in 2011 until March 31 in 2012) or 100 Bq/kg (the new standard, after April 1 in 2012), the relevant municipalities are requested to restrict shipments, based on instructions issued by the Director-General of the Nuclear Emergency Response Headquarters in Japan. This paper describes the polluted situation of the agricultural, livestock, forest and fishery products based on the results of the monitoring for 3 years after the nuclear accident. And soybean is one of the agricultural products, and the radiocesium concentration is higher than the other agricultural products. We analyzed the absorption process in soybean in contaminated areas.

## 2.2 Radiocesium Concentrations in Agricultural, Livestock, Forest and Fishery Products for Three Years After the Nuclear Accident in Fukushima Prefecture

The investigative program required almost 1 week for each item: agricultural, livestock, forest and fishery products. The extracted samples were washed with tap water and the edible portions were chopped finely. The samples were packed in



**Fig. 2.1** Monthly number of samples

a container and were measured using the germanium semiconductor detector (CANBERRA) at Fukushima Agricultural Technology Centre. The detection limit for radiocesium was approximately 10 Bq/kg. Approximately 500 items, were monitored to produce 67,000 data points by the end of March 2014 (Fig. 2.1). We considered the samples that were harvested from March to June 2011, from July to March 2012, from April 2012 to March 2013, from April 2013 to March 2014 (Table 2.1). The radiocesium concentration in each items were classified as below 10 Bq/kg, from 10 to 100 Bq/kg, from 100 to 500 Bq/kg, and >500 Bq/kg. The results of the monitoring have been released on the homepages of Fukushima Prefecture and the Ministry of Health, Labour, and Welfare, Japan.

Fukushima Prefecture: <http://www.new-fukushima.jp/monitoring.php>.

Ministry of Health, Labour, and Welfare: <http://www.mhlw.go.jp/stf/houdou/2r9852000001m9tl.html>.

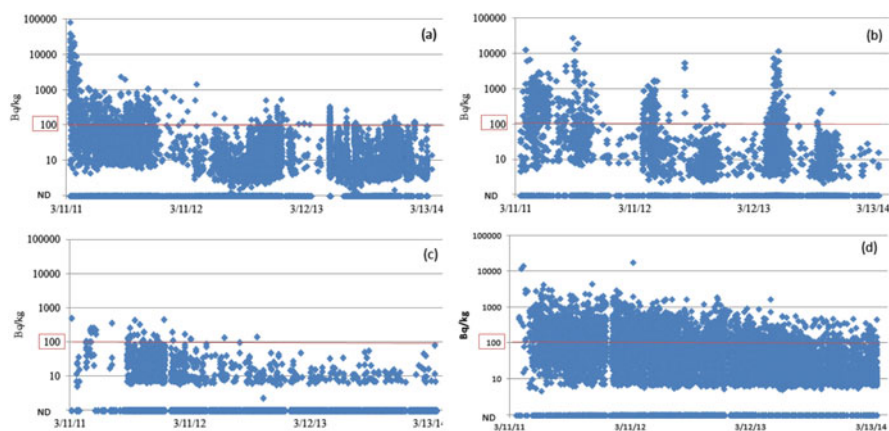
### 2.2.1 Agricultural Products

Agricultural products include cereals (soybeans, adzuki beans, buckwheat, wheat, etc., rice is described at a different chapter.), vegetables (spinach, cucumbers, carrots, tomato, etc.), and fruits (peaches, apples, pears, etc.). Figure 2.2 shows the concentration of radiocesium and radioiodine in the samples harvested from March 2011 to March 2014. Concentrations of radiocesium in agricultural products were the highest immediately after the nuclear accident and rapidly decreased within the first 3 months. The ratio in which radiocesium concentration exceeded the 100 Bq/kg from March 2011 to June 2011 was 18 %, and the maximum value was 82,000 Bq/kg. After July 2011, these concentrations decreased sharply. The ratio in which radiocesium concentration exceeded the 100 Bq/kg was 3 % from July 2011 to March 2012, 0 % from April 2012 to March 2013, and 1 % from April 2013 to March 2014. Higher radiocesium concentrations in agricultural products were observed in soybean, wasabi, plums, kiwis. Radioactive pollution of agricultural products could be divided into direct pollution, in which substances are deposited directly onto the agricultural products, and indirect pollution, in which

**Table 2.1** Radiocesium concentration after Fukushima DNPP accident

Period			Agricultural products	Forest products	Livestock products	Fishery products
3/17/2011~6/30/2011	Number of samples		1496	430	387	321
	<10 Bq/kg	%	66	36	85	14
	10~100 Bq/kg	%	16	16	12	34
	100~500 Bq/kg	%	10	26	3	36
	500 Bq/kg<	%	8	23	0	16
	Max	Bq/kg	82,000	13,000	510	14,400
7/1/2011~3/31/2012	Number of samples		5186	653	5501	3236
	<10 Bq/kg	%	79	56	90	24
	10~100 Bq/kg	%	17	30	9	41
	100~500 Bq/kg	%	3	9	0	27
	500 Bq/kg<	%	0	5	0	5
	Max	Bq/kg	2400	28,000	460	18,700
4/1/2012~3/31/2013	Number of samples		9450	1180	6895	6895
	<10 Bq/kg	%	90	60	99	46
	10~100 Bq/kg	%	9	32	1	41
	100~500 Bq/kg	%	0	6	0	12
	500 Bq/kg<	%	0	2	0	2
	Max	Bq/kg	1460	5600	146	1004
4/1/2013~3/31/2014	Number of samples		10,378	1465	5476	8497
	<10 Bq/kg	%	85	69	99	72
	10~100 Bq/kg	%	14	25	1	25
	100~500 Bq/kg	%	1	4	0	3
	500 Bq/kg<	%	0	2	0	0
	Max	Bq/kg	342	11,870	83	1720

agricultural products absorb substances from the soil through their roots. Direct pollution has a greater impact than indirect pollution. The data after July 2011 inspected mainly the agricultural products that had been grown after the nuclear accident, and the impact of the radiocesium was mainly indirect pollution. Therefore, these concentrations decreased sharply. A little samples showed a higher radiocesium concentration than 100 Bq/kg after April 2012, this might be because these samples were grown with using the agricultural materials which were left outside during the nuclear accident.



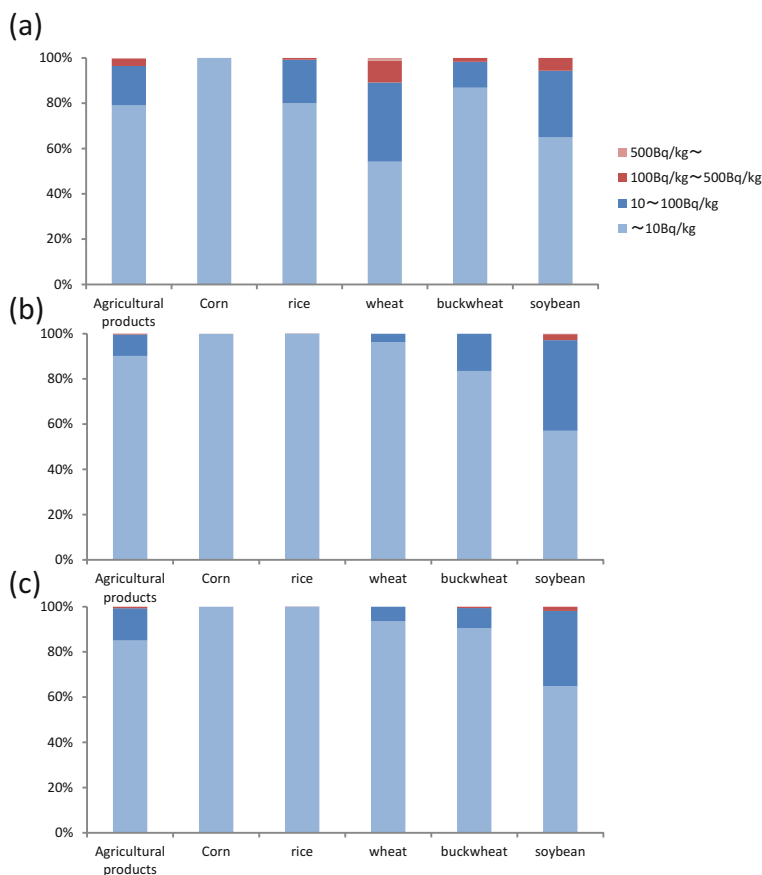
**Fig. 2.2** Progress of radiocesium concentration after Fukushima DNPP accident. (a) agricultural products, (b) forest products, (c) livestock products, (d) fishery products, ND not detected, 100 Bq/kg: the new standard value of radiocesium concentration

## 2.2.2 Radiocesium Absorption in Soybean

Soybean is the global production volume is approximately 250 million tons. This is the fourth largest production volume after wheat, rice and corn. According to monitoring inspection, the ratio of samples exceeding the new standard value of radiocesium (100 Bq/kg) was found to be 5.7 % for soybean, 2.6 % for rice, 11 % for wheat in 2011, 2.6 % for soybean, 0.0007 % for rice and 0 % for wheat in 2012, 1.9 % for soybean 0.0003 % for rice, 0 % for wheat in 2013 (Fig. 2.3). In other words, the monitoring inspections indicated that the ratio of soybean that had exceeded 100 Bq/kg was high compared with rice and wheat for 3 years and that the tendency for decline was low compared with rice and wheat. There are cultivation areas of soybean following rice. In order to make recovery and revitalization of agricultural industries, analysis of the absorption process in soybean was conducted by cultivation in contaminated areas.

### 2.2.2.1 Absorption of Radiocesium in Soybean in the Contaminated Areas

To study the absorption process of soybean in the contaminated areas, soybean (var. Fukuibuki) was grown by no fertilizing in Iitate Village, Fukushima Prefecture on June 29, 2013 (Fig. 2.4). The radiocesium of the field was approximately 13,000 Bq/kg (depth 15 cm), exchangeable potassium was 15.8 mg/100 g, and pH was 6.2.



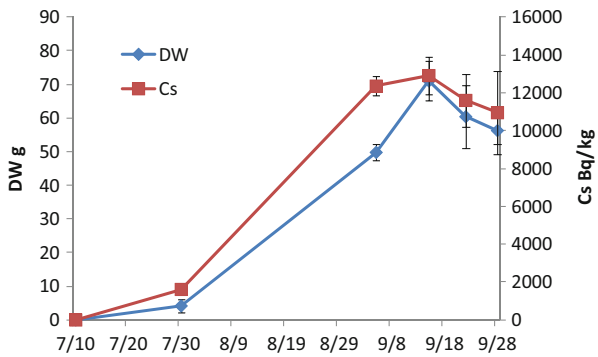
**Fig. 2.3** The ratio of radiocesium concentration in the monitoring inspection for 3 years (a) 2011, (b) 2012, (c) 2013

The radiocesium absorption in soybean was observed from the initial stage of growth, and the absorption increased together with the weight of the above-ground portion until the middle of September (maximum growth period) (Fig. 2.5). Soybean continues nutrient growth even after the flowering period, and the period of continuing nutrient growth is thought to be when radiocesium is being absorbed. When the concentration of radiocesium was measured for each part of the plant at the middle of September, the differences were observed. The radiocesium concentration of the above-ground part was observed: lateral root  $>$  leaf  $\approx$  petiole  $\approx$  pod  $>$  stem  $\approx$  main root (Fig. 2.6). For the concentration of potassium, which is a homologous element of cesium, the following was observed: petiole  $>$  pod  $>$  leaf  $\approx$  stem  $>$  main root  $\approx$  lateral root. There was a difference in concentration ratio of radiocesium to potassium. The difference in distribution within the plant between radiocesium and potassium has

**Fig. 2.4** Soybean in Iitate Village



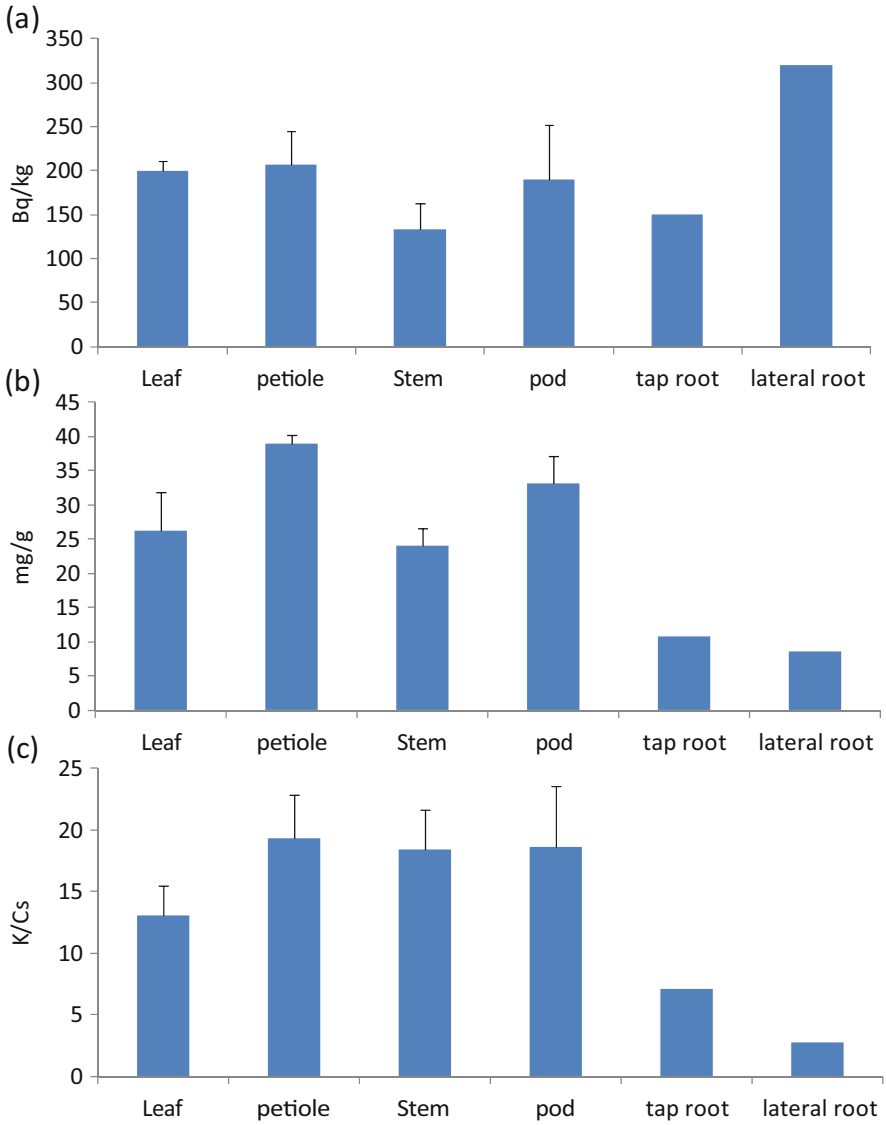
**Fig. 2.5** The progress of radiocesium absorption and dry weight in soybean



been pointed out for rice (Tsukada et al. 2002), and the distribution of soybean is similar to rice.

### 2.2.2.2 Differences Between Soybean Variety

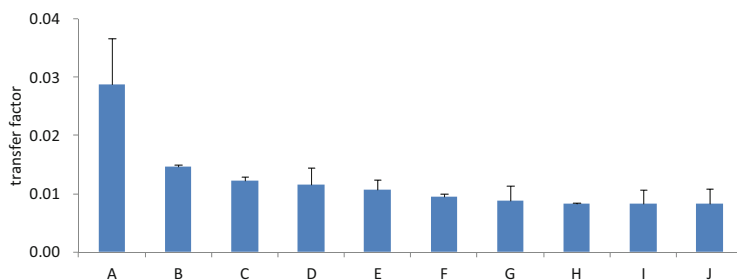
If there is a difference in radiocesium absorption between varieties, it would offer the reduction technology of radiocesium absorption that could immediately be introduced in the contaminated areas, and it would be expected that varietal difference leads also to the mechanism elucidation of cesium absorption. The differences in radiocesium absorption between varieties have been conducted on rice (Ohmori et al. 2014). In this paper, the absorption of radiocesium was studied comparing 10 varieties of soybean in Iitate Village, Fukushima Prefecture. The samples were parental lines that held cross-fertilization later generations, varieties A (wild soya bean) and B which were obtained from the National BioResource Project, and cultivation varieties which had grown inside Fukushima Prefecture (C to J).



**Fig. 2.6** The radiocesium and potassium concentration of soybean (22 Sept 2013). (a) radiocesium concentration, (b) potassium concentration, (c) K/Cs

Figure 2.7 shows the transfer factor to grain of different varieties. When compared with the parental line A and B, A showed a tendency to be about twice as high as B. The transfer factor of the C to J did not have a large difference. No clear tendency based on the grain size was observed. No clear correlation between the grain radiocesium concentration and the grain potassium concentration was





**Fig. 2.7** Transfer factor to soybean grains of different varieties

observed. We plan to use later generations of cross-fertilization between A and B to study the genetic locus involved in the absorption of radiocesium.

### 2.2.2.3 Distribution of Cesium in Soybean Grain

To study the distribution of radiocesium in soybean grain, sections of soybean grain cultivated using liquid culture medium with added radiocesium ( $^{137}\text{Cs}$ ) were contacted to an IP (imaging plate, Fujifilm Co.), and autoradiography was obtained. The radiocesium inside the soybean grain was distributed generally uniformly throughout the entire grain. For the radiocesium of the rice grain, it was reported that radiocesium was topically higher in the embryo and aleurone layer, and we have shown that radiocesium distributions inside soybean and rice are different. This is considered to be due to the difference in seed storage tissue. The rice grain stores nutrients (include potassium) in the embryo, and starch and protein is accumulated in the endosperm. We guess the radiocesium stores in the embryo rather than in the central part of the rice grain. However, as the soybean grain is an exalbuminous seed, the nutrients, starch and lipids accumulate in the cotyledon, which comprises a large portion of the seed. Thus, the nutrients store uniformly inside the grain, and it is thought that the cesium, like the other nutrients, is distributed uniformly inside the grain. The form in which nutrients accumulate is different between rice and soybean, and the mineral constituent of soybean is about five times that of rice. The high accumulation of nutrients inside the grain is thought to be one factor for the high accumulation of cesium in soybean.

## 2.3 Livestock Products, Forest Products, Fishery Products

Livestock products include beef, pork, raw milk, chicken eggs et al. Monitoring of radioactive concentrations in livestock products began with raw milk immediately after the nuclear accident. Radioactiveiodine that exceeded the provisional regulation level (2000 Bq/kg) was detected in raw milk between March 2011 and June

2011 (data not shown). Beef which were over 500 Bq/kg of radiocesium concentrations were detected between March 2011 and June 2011 (Fig. 2.2). But both radioactive iodine and cesium of livestock products decreased from July 2011. Beef which were over 500 Bq/kg of radiocesium concentrations might have been due to the supply animals with the polluted feeds by radiocesium. The government and Fukushima prefecture have called farmers not to feed hays and grass that was outside at the nuclear accident to prevent further contamination of livestock products.

Forest products include edible wild plants (bamboo shoots, fatsia sprouts, etc.), mushrooms. Measurements for cesium in forestry products began in late March 2011, which is also the beginning of the harvest season for edible wild plants. The ratio in which radiocesium concentration exceeded the 100 Bq/kg was 49 % from March 2011 to June 2011, 14 % from July 2011 to March 2012, 8 % from April 2012 to March 2013, and 6 % from April 2013 to March 2014 (Fig. 2.2). This result identified a high trend in radiocesium concentrations for forestry products compared to agricultural or livestock products. Radiocesium concentrations remained high even after July 2011, suggesting that forestry products were not only polluted directly with radiocesium released from the nuclear disaster, but also indirectly with the absorbed radiocesium from the soil. Especially bamboo shoots, '*koshiabura*' (*Acanthopanax sciadophylloides*), fatsia sprouts (*Aralia elata* Seem.), and wild mushrooms were detected with high radiocesium concentrations.

The ratio of fishery products in which radiocesium concentration exceeded the 100 Bq/kg was 52 % from March 2011 to June 2011, 32 % from July 2011 to March 2012, 14 % from April 2012 to March 2013, and 3 % from April 2013 to March 2014, and the maximum value was 18,700 Bq/kg (Fig. 2.2). This result indicates that radiocesium concentration of fishery products have been falling every year, but high concentration remain as well as forestry products. There are difference according the kind of fish, octopus and squids are low, on the other hand cod and stone flounder are high.

Four years have passed since the accident, and we expect to see the sequential reopening of agriculture even in the evacuated regions. In order to provide safe agricultural crops, not only do we think it is necessary to continue monitoring tests, but we would also like to continue research that contributes to the efforts of agricultural recovery and revitalization in the areas contaminated by the nuclear accident.

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